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Higher Inherent Visual Contrast in Polarized Images Generated from Remotely Sensed Field Data

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ABSTRACT

A simple procedure for generating photographs is reported showing polarizing effects of reflecting surfaces from the photos taken with a photographic camera with a polarizer and also from the digital output of a radiometer with a polarizer. Photos generated by displaying the degree of polarization (DOP) of light reflected from the surfaces of objects at each point in both cases have provided higher inherent visual contrast, revealing details which are not available in intensity images of remotely sensed data. DOP image is expected to provide additional invaluable supplementary information of defence interest, which is otherwise not available. Possible applications and limitations of the procedure are discussed.

1. INTRODUCTION

In the currently used remote sensing techniques, variation in diffusely reflected radiance is used to discriminate various objects. But light can be described in terms of its intensity and the state of polarization. The information content in polarized data has been considered as additional supplementary information to that contained in remote sensing data. Its potential applications[1-14] and limitations have also been discussed. Such information derived from laboratory or ground studies is usually given as tables of Stokes parameters in different wavebands or as plots of degree of polarization (DOP) against wavelength, view angle and incidence angle and observation azimuth[6]. But this information is not being routinely acquired in remote sensing.

In this laboratory scale study, an attempt has been made to adopt a simple procedure for acquiring remotely-sensed radiance data using a sensor and a linear polarizer under the same geometry of illumination and observation for obtaining useful results. This approach generates two similar signals from the same point/scene as compared to one signal in remote sensing techniques. The DOP of the reflected beam of light, displayed on photos, has been calculated using the following equation[15,16]

$$P = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \tag{1}$$

where

P Degree of polarization

I_{max} Maximum transmitted intensity through a linear polarizer

I_{min} Minimum transmitted intensity through a linear polarizer

For measuring specular reflection on a clear day, the incident ray, the normal to the surface and the reflected ray must lie in the same plane with the angle of incidence equal to the angle of reflection. The reflected beam of light consists of a linearly

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polarized component due to specular reflection and a randomly polarized component. By rotating a linear polarizer in the reflected beam of light, the linearly polarized component can be filtered. In the case of highly specular objects, $I_{max} >> I_{min}$.

The objects made of smooth, plain, painted metallic surfaces have been used, except the freshly deposited MgO and sand patches. Therefore, for comparing the information available from remote sensing and the present study, I_{max} and I_{min} can be considered to represent specularly and diffusely reflected components respectively of the light reflected from highly specular surfaces, as an approximation, for practical purpose.

2. PROCEDURES

Procedures have been described for displaying (i) the polarizing effects of various objects generated from the output of an single lens reflection (SLR) camera attached with a linear visible polarizer and (ii) the grey levels of plain objects generated from the output of a field radiometer attached with a linear near-infrared polarizer.

2.1 Generation of Photographs Displaying Polarizing Effects

2.1.1 From Field Radiometric Data

On a clear sky day, plain metallic sheet of size 50×70 cm^2 (object), uniformly painted with a commercially available enamel paint, was placed in a horizontal plane in an open field. A ground truth radiometer, field of view (FOV) 1°, of Exotech Inc. model 100-BX attached with a linear NIR polarizer (Halbo Optics) and mounted on a three-axis rotating tripod stand, was aligned at a height of 1.5 m above the surface of the object to receive specularly reflected radiance, in the wavelength region 0.804-1.045 µm from the surface of the object. The object acts as a polarizer and a linear polarizer as an analyser. The polarizer was manually rotated in steps and radiance data were collected on a programmed polycorder (Omnidata International Inc.) without changing the position of the radiometer. After collecting the data, the object was replaced by another object of a different colour. To collect data under similar conditions of illumination, the lengths of shadows of a vertical needle of 10 cm were precalculated for a sun elevation of 50 ± 1° and marked on a horizontal plane. Data on all the objects were collected during this period on a number of clear sky days without changing the set-up. The choice of sun elevation angle was arbitrary. Solar irradiation during the measurement period was also checked by another radiometer. These data were transferred on a floppy diskette by X-Talk for generation of photo outputs. A software has been developed for the creation of data files of I_{min}, I_{max}. From these data DOP was calculated using Eqn (1). Photo outputs, displaying grey levels of data files of I_{min}, I_{max} and DOP were generated by giving default colours of the image processing system (VAX 11/780) by Dunn camera at RRSSC, Jodhpur.

In this display

Digital number (DN) = 1 represents 0.9 X (minimum value of I_{min} in all the data files) and

DN = 255 represents 1.1 X (maximum value of I_{max} in all the data sets) on all the objects in image files of I_{min} and I_{max}.

DN value = 1 represents DOP = 0 and

DN = 255 represents DOP = 1 in the image file of DOP. Multiplication factors 0.9 and 1.1 are arbitrary for creating images.

2.1.2 Using SLR Camera

To discriminate partial diffusers of varying degrees of specularity but of the same diffused reflectance, plain metallic sheets painted with commercially available enamel paints of different colours, sand patches, a piece of plastic net and a glass sheet with MgO freshly deposited on its surface were placed in a horizontal plane for studies. Area covered by the objects was 50×70 cm^2. An SLR camera (Cannon) attached with a

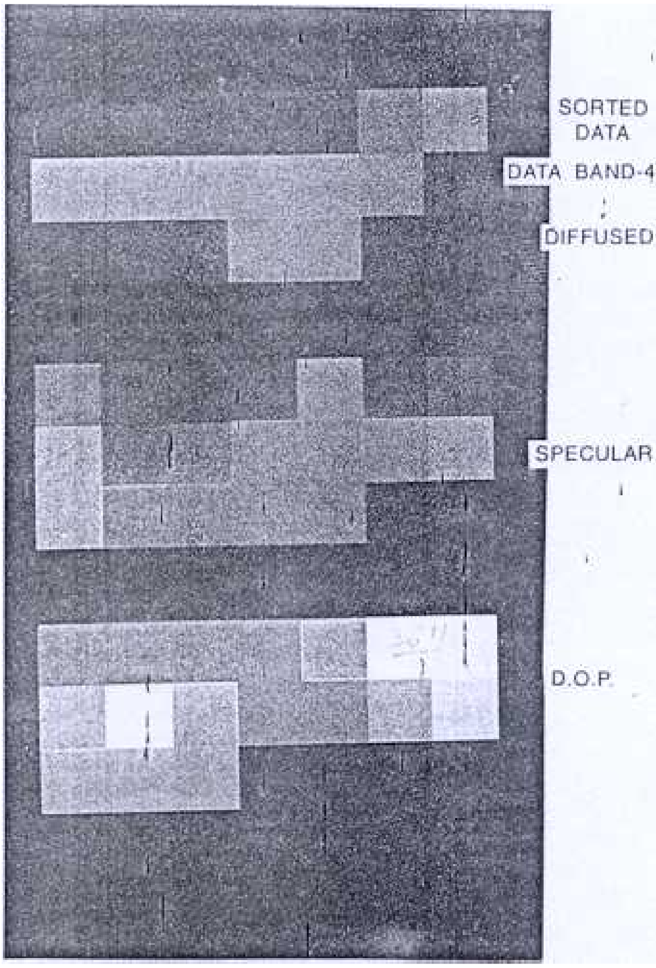


Figure 1. Gray level display of average radiance of objects in 0.804-1.045 μm generated from the digital output of a radiometer attached with a linear NIR polarizer.

linear visible polarizer mounted on a three-axis rotating tripod stand was aligned to receive the specularly reflected beam of light at a height of ~ 6 m and a distance of ~ 20 m from the surfaces of the objects using a continuously variable height platform. Photographs representing maximum (I_{max}) and minimum (I_{min}) intensities of light transmitted through the linear polarizer (visual observation through camera) were quickly taken by rotating the transmission axis of a linear polarizer in front of the camera lens with camera settings in auto mode.

These two photos were digitized with a resolution of 100 μm and then the digitized data were transferred on CCT. Digital images representing I_{min}, and I_{max} were registered precisely, point by point comparison was done and DOP at each point was calculated using Eqn (1). Then images representing I_{min}, I_{max} and DOP at each point were generated by giving default colours at RRSSC, Jodhpur.

In this display

DN = 1 represents DOP = 0 and

DN = 255 represents DOP = 1 in the image file of DOP and digitized values as DN in image files of I_{min} and I_{max}.

3. RESULTS & DISCUSSION

Results of studies on linear polarization of light reflected from the surfaces of plain objects, as described above, have been presented as photographs of full screen video output 512 × 512 pixels.

In the study using the radiometer, it has been estimated that change of ±1° in the angle of incidence due to change in sun elevation 50° causes measurement error in DOP by 7 per cent. Figure 1 consists of three blocks of 19 squares; each square in the top block displays average grey level of an object created in data file of I_{min}, calculated from radiometric data. The software has an arranged sequence of grey level display in increasing order in the data file of I_{min} and the corresponding values have been displayed from data files of I_{max} in the middle block and DOP in the bottom block. The first five squares in the top block have very low diffused intensity. This sequence has been arranged for the ease of interpretation. The photograph shows results of the study in 0.804 - 1.045 μm wavelength region. Maximum DOP is displayed at locations 1, 2, 3, 4, 11 and 12 and zero at locations 18 and 19. Comparison of neighbouring locations 9, 10, 12 and 13 reveals a distinctly higher inherent visual contrast in DOP display.

Figure 2 has three images of various objects generated from the output of the SLR camera (layout given in Fig. 3). In specular reflection, light waves of all the wavelengths are reflected from smooth surfaces and therefore smooth coloured

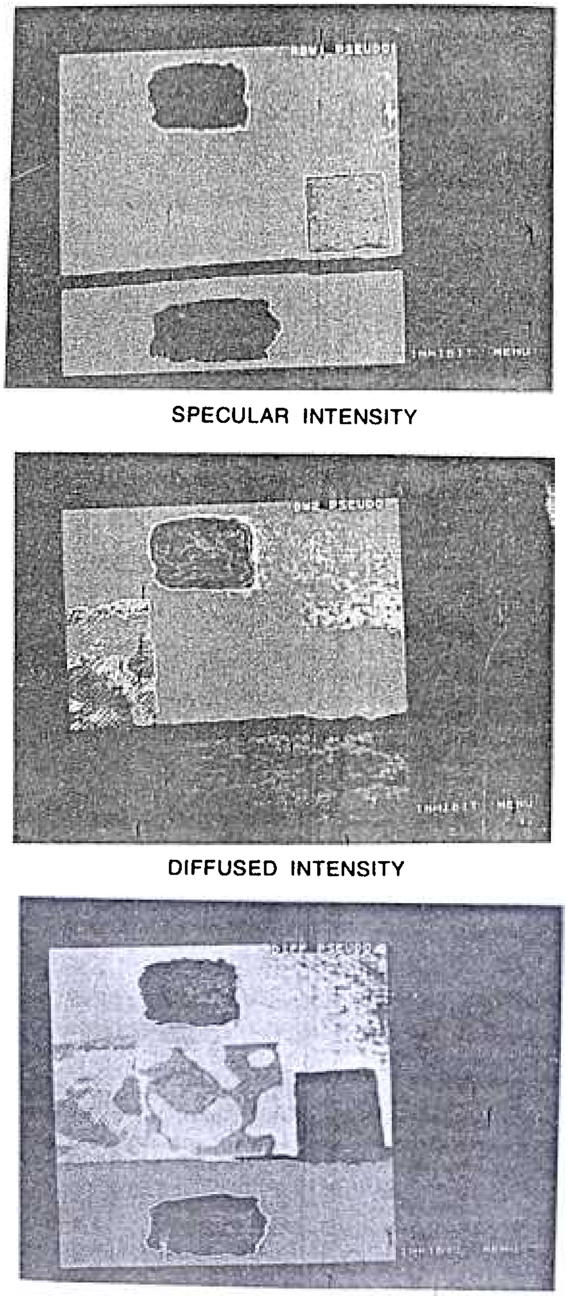
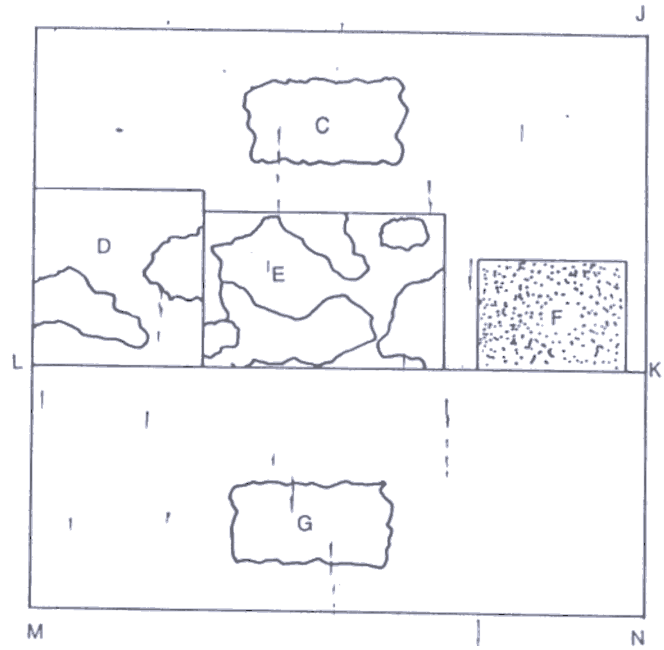


Figure 2. Polarization photographs generated from the output of an SLR camera attached with a linear polarizer.

surfaces appear white when seen in a direction opposite to the sun. The top image, representative of specular reflection (I_{max}), shows two sand patches on two painted metallic sheets and a freshly prepared MgO coated plate. In this image, a net and a disruptive pattern are not visible. The middle



IJKL	YELLOW PAINTED PLAIN METALLIC SHEET
KLMN	RED PAINTED PLAIN METALLIC SHEET
C & G	SAND PATCHES
D	A PLASTIC NET ON DISRUPTIVELY PAINTED PLAIN METALLIC SHEET
E	DISRUPTIVELY PAINTED PLAIN METALLIC SHEET
F	GLASS SHEET WITH FRESHLY DEPOSITED *MgO*

Figure 3. Layout of objects in figure 2

image is representative of diffuse reflection (I_{min}) from the same objects under identical conditions, except that transmission axis of the linear polarizer (analyser) has been rotated by 90°, in which a net, a sand patch on one painted metallic sheet and contour of a disruptively painted object and a freshly prepared MgO coated plate are clearly visible, but the other sand patch on another painted metallic sheet is not seen, indicating the same diffused reflectance of sand and sheet. It is to be noted that all features of the complete scene are not visible in any of these images. The third image, which represents DOP at each point, shows all the objects with complete details that are not apparent in either the top or the middle image.

Experiments were designed to prove the feasibility of the procedure by taking measurements on two-dimensional objects for relative analysis keeping the same geometry of illumination and observation. Both the above approaches have provided three images of the same point for comparative analysis in which a higher inherent visual contrast is recorded in DOP image. Some inherent errors[6] in measurement and processing, such as registration, control of illumination and film development, difficulty in attributing changes in polarization azimuth to the angle of changing surface conditions, image geometry causing variations in recording the DOP across the FOV of the sensor independent of variations in surface properties are of serious nature. The maximum polarization will be observed only at one point, and away from this point, the degree of polarization will decrease.

It is difficult to overcome these problems when data are acquired at different times. The above inaccuracies in the present polarization displays have been minimised through quick photography on the same film maintaining the same geometry of illumination and observation and by quick collection of data on programmed polycorder without changing the view angle of the radiometer and the position of the objects, as described. According to Prosch, *et al*[14]. video polarimetry provides quick look analysis capability in different display modes and enables generation of high resolution wide FOV polarization maps in real-time. The DOP might be another useful source of information.

Qualitative analysis on the basis of these data would be valid if the data are acquired at non-normal angles of incidence by imaging device for real-time relative analysis. It is felt that relative analysis of objects of varying degree of specularity can be done by using a camera or a sensor with scanning mechanism for all those objects whose surfaces can be assumed as two-dimensional, depending on the distance of observation. Useful interpretable results of defence interest can be obtained from aircraft altitudes.

4. CONCLUSION

This experiment has successfully displayed higher inherent visual contrast in photos generated by displaying DOP at each point by using SLR camera and polarizer in the visible region and also a radiometer and a polarizer in the near-infrared radiation (NIR) region. Thus, this simple procedure demonstrates the qualitative potential of single parameter DOP display for relative studies in the optical region and for obtaining additional supplementary information to discriminate objects of similar diffused reflectance on the basis of variations in their specularity, which is not possible by the currently used remote sensing techniques. Military objects have strongly specular plain portions and relevant data are of specific defence interest, i.e., conditions for the same radiance of objects and background as well as their possible detection. Approach displays high potential, as military objects are not visible in certain backgrounds in intensity-based images.

On the basis of the above results, it is logical to conclude that this approach of single parameter DOP display is suitable for obtaining useful aerial data for detection and concealment in the optical region through appropriate selection of FOV and distance of observation for a typical geometry of illumination and observation. Real-time relative analysis is possible by a two-sensor system attached with the polarizers transmission axis set at 90^{o} to each other.

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